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(19) THE PATENT OFFICE LONDON

(54) METHOD AND APPARATUS FOR REMOVING CONTAMINANTS FROM LIQUIDS

(71) We, NORTH AMERICAN ROCKWELL CORPORATION, a corporation organized and existing under the laws of the State of Delaware, United States of America, of 1700 East Imperial Highway, El Segundo, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to improvements in an electrical apparatus for removing suspended, dispersed liquid contaminants from streams of fluids which are substantially non-conductive to the passage of electrical current, e.g., hydrocarbon fuels, organic cleaning agents such as chlorinated hydrocarbons and other organic fluids having a low dielectric constant including solvents, gasoline and oils; the contaminated fluid being passed through an applied electric field to accomplish the removal of the contaminating liquid.

It is frequently necessary to remove liquid contaminants such as water or aqueous solutions of salts from fuels or other fluids if these fluids are to be suitable for their intended use. As an example, suspended and dispersed water droplets in aircraft fuels may freeze, forming ice crystals which will plug fuel lines and interrupt the flow to the engine. Gross quantities of dispersed water carried in the fuel stream may cause engine failure or malfunction. Where the entrained water contains dissolved salts, corrosion of fuel system components may also result. Various means have been employed to remove this form of contamination. Mechanical filters described as filters/separators have been and are being used for this purpose for various fuels in internal combustion engines. However, these suffer loss of effectiveness if surface active materials are introduced into the fuels.

Alternatively, the passage of such contaminated fluids through an electrical field has been employed as a means of causing coalescence of dispersed aqueous contaminants, facilitating their removal from the fluid stream by gravity separation or other mechanical means. The beneficial effects of such electrical fields have been variously described as resulting from induced dipole coalescence, electrophoresis, and dielectrophoresis.

In the case of electrophoresis, dispersed contaminant particles bearing a charge are attracted to an oppositely charged electrode and are then removed from the stream. (See Auderbert & deMende. *The Principles of Electrophoresis*. London, Hutchinson, 1959). In the other instances, the beneficial effect of electrical fields is attributable largely to forces arising from dipole orientation in the field. See Waterman, *Chem. Eng. Prog., 61,* 51 (1965)). The effectiveness of the electrical fields in such cases is therefore dependent upon a substantial difference in the dielectric constants of the dispersed matter and of the host fluid to be clarified. Many organic fluids such as hydrocarbon fuels have relatively low dielectric constant. While the following description will refer frequently to coalescence and separation of dispersed water from hydrocarbon fuels, it will be understood that the principles described herein may be applied also to the removal of the kinds of liquid contaminants from immiscible liquids where substantial difference in the dielectric constants of the two liquid materials exists.

A number of electrical devices are known in the prior art which utilize one or more of the above discussed effects. All of the electrical field effects described above have been indicated to be mechanisms for coalescence of liquid contaminants and removal of dispersed solid matter although varying degrees of emphasis are placed on the specific mechanism. Electrophoresis is specifically cited as a major contributor to the removal of particulate contaminants in U.S. Patents 3,205,160; 3,205,161; 3,252,884;

and 2,849,395, and is inferred by others. Ionization by discharge from pointed electrodes is described in U.S. Patents 3,074,870; 3,129,157; and 3,247,091, the ionization resulting in attraction of the resulting charged particles to an electrode having an opposite charge; while U.S. Patent 3,314,872 describes the establishment of an emulsion-breaking field by generation of a static charge created by forcing the fluid through a porous plug. Generally, the prior art describes the benefits to be derived from a particular electrode geometry, various field intensities, and hydrodynamic flow regimes to facilitate separation of coalesced material by gravity. Desalting of crude oil by water additions is also described in U.S. Patent 3,129,157. The present invention provides improvements over these prior art methods and arrangements.

According to the invention there is provided emulsion treating apparatus for decreasing the concentration of dispersed contaminant in a substantially nonconductive liquid, comprising first and second electrodes having spaced, facing surfaces substantially parallel to each other and defining therebetween a channel for the liquid, means for applying an alternating or interrupted electric field between the first and second electrodes and across the channel, and means for enhancing the separation of the contaminant from the liquid in the channel through the action of the electric field, the last named means including an insulating covering isolating at least one electrode from the non-conductive liquid and further including a fuzzy hydrophilic substance (as herein defined) positioned on only one of the electrodes so that coalescence of the contaminant is promoted.

The present invention is particularly applicable to the treatment of hydrocarbon fuels by an electrical device where the possibility of an explosive mixture of air and fuel may result from the accidental entrance of air into the device during periods of inactivity and where an electrical discharge between electrodes would therefore create an exceptionally hazardous condition. The prior art employs electrodes spaced a sufficient distance apart to minimize the hazard of electrical shorting between charged electrodes. These devices are well suited to the continuous treatment of crude oils but are not well suited to the treatment of more refined and flammable products such as gasoline for the reason cited above.

For certain purposes, e.g., treatment of refined products or cleaning fluids, the flow rate of the fluid to be treated is small, as compared to that common to the treatment of crude oil. In such instances, it is desirable that the treating device be as small and compact as possible, making the expedient of widely-spaced electrodes as described in the prior art undesirable. As the voltage gradient is an important factor in the effectiveness of the treating device, it is also apparent that much higher voltages are required for such widely spaced electrodes. Further, the passage of substantial quantities of current through the fluid will, if the contaminating liquid is water or an aqueous solution, result in electrolysis generating an explosive mixture of hydrogen or oxygen gas, creating an explosive hazard even if the main constituent of the stream to be treated is substantially non-explosive.

The present invention avoids the hazards of explosion or excessive power consumption through inter-electrode arcing by electrically isolating the high voltage electrode from the stream to be treated. Electrically isolating, e.g., by an insulating coating, the high voltage electrode employed to generate an electrical field precludes any electrophoretic effect since it is not possible to discharge electrically charged contaminant particles if the insulating coating is adequate to prevent the passage of a significant amount of current. For this reason, the continuing application of unidirectional electrical fields to various contaminants from fluids such as fuel oils has little value in the present invention when one or both electrodes possess a non-electrically conductive coating.

In the known prior art, U.S. Patent No. 2,849,395 cites benefits to be derived, using non-insulated electrodes, from the application of various types of electrical fields including pulsed direct-current and alternating-current electrical fields of high frequency, but notes that frequencies as low as 25 Hz may be used. It has been found that high alternating frequencies, e.g., 6000 Hz, are generally ineffective in coalescing finely dispersed water in No. 2 diesel fuel oil, yet U.S. Patent No. 2,849,395 states that frequencies as high as one million Hz provide effective treatment where electrical discharges are deliberately sought from non-insulated electrodes. Therefore, insulating one or both electrodes requires certain electrical fields other than those taught for non-insulated electrodes. In the present invention, the application of an alternating field such as that produced by 60 Hz a.c. has, however, been found to produce coalescence of finely dispersed water in hydrocarbon fuels, presumably by induced dipole effects.

For the purposes of this specification, the following definition is applicable: the meaning of a fuzzy hydrophilic substance is a substance which is preferentially wetted by the contaminant to be removed rather than by the material comprising the stream being purified and whose surface is composed of a multitude of fluffy particles or fibres, e.g. felted fibres.

Brief Description of the Drawings

Fig. 1 is a schematic diagram of a system in which the method and apparatus for the present invention is used.

Fig. 2 is a schematic diagram and sectional plan view of the apparatus and flow path of a liquid being treated in accordance with the present invention.

Fig. 3 is an exploded view of the preferred embodiment of the present invention.

Fig. 4 is a sectional end view of the embodiment of Fig. 3, shown in assembled relationship.

Fig. 5 is a graph showing the relative performance of electrodes covered with hydrophilic as compared with electrodes not having a hydrophilic covering.

The system in Fig. 1 shows the present invention adapted for use in a fuel storage system in which fuel transported by a ship, barge, or other bulk shipping device 10 is emptied through pump 11 to storage tank 12. During the transportation and long storage periods condensed water or sea water becomes mixed with the fuel and represents a potentially dangerous contaminant, particularly where that fuel is aircraft fuel. Since the presence of water in such fuel can result in engine failure, the removal of such a contaminant prior to use and in reasonable proximity to the intended use as a fuel significantly increases safety in aircraft use. Thus, a contaminant-removing separator 13 is introduced into the system thereby providing a means for removing immiscible contaminants such as water from aircraft fuel. While the presence of water in other fuels represents less of a hazard to life, this contaminant may result in engine malfunction and economic loss.

The separator 13 is preferably of the type shown schematically in Fig. 2. Specifically, a closed electrically insulating container 15 is provided with an inlet 16 for the dielectric liquid to be treated, an outlet 17 for the treated liquid, and a drain 18 for removal of the contaminant (e.g., water) separated by the electrical field deflect imposed on the liquid flow channel 19. Adjacent the sides of the channel 19 are two plate type electrodes 20 and 22. While the preferred embodiment utilizes plate type electrodes, it is within the purview of the present invention to utilize a concentric electrode relationship or other types well known in the art. The electrode 20 is connected through ground lead 24 to a voltage source 26 (See Fig. 1) and has its working surface 28 aligned so as to define a substantial portion of one side of the channel 19.

The working surface 28 of electrode 20 has a coating or layer 30 of hydrophilic material at least partially covering the working surface. In order that the function of this hydrophilic coating or covering is more clearly understood, the basic electrical field effect will be described in more detail. Electrically induced turbulence is imparted to the water droplets in the fuel stream by the action of the field. The violent motion of these droplets materially assists coalescence of finely dispersed water. It has been found that the presence of a hydrophilic coating or covering 30 results in the enhancement of such agitation.

The coatings found to produce this beneficial effect appear to be preferentially wetted by water (hydrophilic) rather than by the fuel. These include cotton, glass cloth and a felt consisting of equal parts of wool and viscose rayon fibres. Conversely, PTFE felt, known to be hydrophobic, did not assist de-emulsification in this manner nor did fibrous metal electrodes (felt metal). Aside from the wetting properties of these coatings, some further benefit appears to result from the physical surface characteristics of the coating. Fibrous, fuzzy coatings such as the felt (wool-viscose) provide improved performance over that observed with hydrophilic coatings having relatively smooth surfaces (cotton, glass cloth). The points or projections provided by the rougher surface appear to provide small regions of intense electrical fields increasing turbulence in such regions.

Disposed in opposing relationship to the electrode 20 with coating 30 in Fig. 2 is the high voltage electrode 22 connected through lead 32 to voltage supply 26 (See Fig. 1). The working surface 34 of electrode 22 is coated or covered by a layer of electrically insulating material 36 so as to completely electrically isolate the electrode 22 from any liquid present in channel 19. The electrode 22 is aligned so as to define a substantial portion of one side of the liquid channel 19.

In general, the operation of the schematic arrangement of Fig. 2 is as follows: the liquid to be treated is pumped through inlet 16, down the channel 19 and through outlet 17. During its travel down channel 19, which may have any desired length, the application of an electric field between electrodes 20 and 22 causes the dispersed liquid droplets to coalesce and accumulate so that liquid rich in contaminant material can be removed through drain 18. In this manner, after one or more stages of application of the electrical field effect by the arrangement of Fig. 2 the treated liquid has a substantially reduced concentration of contaminating matter.

A detailed structural arrangement showing the preferred embodiment of the present invention is shown in the exploded view of Fig. 3. Referring now to Fig. 3 in detail, the preferred embodiment of the present invention comprises front and back frame members 36 and 38, respectively, between which are clamped the various components defining an operative cell arrangement. Located between these two frame members 36 and 38 is a front

plate 40 having a liquid inlet 41 and a liquid outlet 42 located on opposite ends of its longitudinal dimension. The front plate 40 contains a plurality of apertures 43 around its periphery and through which a plurality of bolts 44 are inserted for holding the various components between the two frame members in sealed relationship. Also provided in front plate 40 is an aperture 45 through which an electrical lead may be passed in sealed relationship as described in detail hereinafter. Adjacent to the inner surface 46 of the front plate 40 is an electrically conductive electrode structure 47 preferably fabricated from one mil stainless steel foil to which electrical lead 48 is connected at a location adapted to pass through aperture 45 in front plate 40. Appropriate sealing means around the lead 48 such as an epoxy resin may be utilized to ensure that a liquid seal is maintained in aperture 45. The electrode structure 47 may be a solid sheet of electrically conducting material having a dimension slightly less than the aperture formed by the rubber insulating gasket 50. However, the preferred structure for the electrode 47 is that shown in Fig. 3 and comprises two or more extending electrode portions 51, 52 and 53 which are integral with a top-connecting portion 54 and develop separate stages in the operative cell. Specifically, an electrode structure having a three inch height, a 7 1/2" length, a depending electrode width and spacing of 1 1/2" each, and a 1/4" top connecting portion 54, has resulted in the operative characteristics shown in Fig. 5 as described in detail hereinafter. While such a top-connecting portion is the preferred arrangement, it is within the purview of the present invention to use a plurality of physically separated extending electrode portions, such as 51, 52 and 53, which are interconnected by electrical leads in place of the connecting portion 54. The primary consideration in the staged electrode structure is to provide a plurality of edges 55 along the channel 19 (See Fig. 2) to enhance the effect of electrical fields utilized to separate the aqueous substances in the liquid flowing through the channel 19, as is explained hereinafter.

The surface of the electrode 47 which is adjacent and exposed to the channel 19, or at least portions of those electrodes 51, 52 and 53, are at least partially covered with a fuzzy hydrophilic covering 56 which further enhances the electrical field effect within the channel 19 as explained above. The electrode 47 is connected to the ground side of the voltage source 26 and is not enclosed or covered with insulating material other than the hydrophilic material 56.

Adjacent the gasket 50 is a channel-forming frame member 57 which abutts the gasket 50 on one side and a similar gasket 58 on its other side. The frame member 57 generally defines the channel 19 through which the liquid to be treated will flow and therefore defines a cavity which communicates directly with inlet 41 and outlet 42. The frame member 57 was 1/4" thick in the example referred to above. It is clear that the structure of the electrode 47 must be smaller than the aperture formed by the frame member 57 so as to not impede the flow of the liquid to be treated along the channel 19. This arrangement is more clearly shown in the schematic diagram of Fig. 2. Channel-forming frame member 57 contains an outlet aperture and pipe 60 through which the accumulated contaminant-enriched liquid may be drained from the lower portion of channel 19.

A solid insulating electrode cover 62, preferably fabricated of polymethylmethacrylate, having a plurality of appropriate apertures 43 along its edge portion is positioned in abutting relation to the gasket 58. The insulating cover 62 electrically insulates an electrode 64 from the liquid in channel 19 formed by the frame member 57 in accordance with the above referenced copending application. The electrode 64 is preferably of the same geometry as electrode 47, i.e., a plurality of edges 59 are formed along the longitudinal channel direction to enhance the edge effect as is explained in more detail hereinafter. However, such edge-forming geometry is not essential to the operability of the present invention. The electrode 64 is preferably formed of a one-mil stainless steel foil although other electrically conducting materials may be utilized. As an added precaution in the event of any leaks, the electrode 64 is enclosed in a 10-mil vinyl plastic insulating sheeting 65 which is heat-sealed around the electrode.

Electrically connected to the electrode 64 is a high voltage lead 66 enclosed in an insulating tube 67 integral with the plastic sheeting 65. The high voltage lead 66 is connected to the high voltage side of the voltage source 26 (See Fig. 1). A solid backing plate 68 preferably made of an electrically insulating material, like the insulating cover 62, supports the electrode 64 in a plane parallel with the plane formed by electrode 47. Thus the channel-forming frame member 57 has parallel sides so that the channel 19 has an essentially constant cross section along its longitudinal dimension except to the extent the hydrophilic material 56 extends into the channel 19.

Adjacent the backing plate 68 is the back frame member 38 which cooperates with front frame member 36 and a plurality of bolts 44 to seal the various elements, including front plate 40, gasket 50, channel-forming frame member 57, gasket 58, insulating cover 62, vinyl plastic sheeting 65, and backing plate 68 into a sealed cell assembly. As

shown in the drawing, each of these members has an appropriate series of apertures 43 through which the bolts 44 are inserted.

The assembled and sealed cell unit is shown in cross section in Fig. 4 where like numbers represent corresponding parts in Fig. 3. It is clear from the cross sectional view of Fig. 4 that the high voltage electrode is completely electrically insulated not only from the opposing electrode 47, but also from the liquid material in the channel 19. Further, it is also apparent that the hydrophilic material 56 is present only on that electrode which is directly exposed to the liquid within the channel 19. It is this combination of features which provides the enhanced electric field effect achieved by the present invention.

Fig. 5 shows the improvement in operation resulting from the combination of one electrically isolated electrode and one hydrophilic coated electrode. The graph of Fig. 5 shows the parts per million of water in an effluent oil, after passing through a cell of the type shown in Figs. 3 and 4, as a function of the flow rate. For the particular example, 2000 ppm of distilled water was initially added to a volume of #2 diesel fuel and passed through the device embodying the present invention. In the case represented by curve 70, the device was operating with one electrode 64 isolated from channel 19 by insulating cover 62 and the other electrode 53 bare, i.e., having no hydrophilic coating or cover. The reduction in the concentration of the liquid (water) in the major liquid phase (diesel fuel) is apparent from curve 71 which shows the results obtained by covering the surface of electrode 53 with hydrophilic material 56. The hydrophilic coating in this case was a 1/16″ thick layer of 50 percent wool and 50 percent viscose rayon cemented to the electrode portions 51, 52 and 53. At low flow rates, e.g., 1 g.p.h., the covering was found to be of little benefit. In both cases a 13 Kv, (peak to peak) 60 Hz voltage was applied between the electrodes 53 and 64. The electrodes were planar and formed a 1/8″ wide channel 19.

It was determined by running the same experiment, except without the application of power, that only the combination of applied power and the hydrophilic coating provided the improved result.

It is apparent from Fig. 5 that at the same flow rate a substantial reduction in contaminant concentration can be achieved merely by providing hydrophilic coating or coverings over at least a portion of one of the electrodes. Thus the present invention provides a method and apparatus for substantially reducing the residence time during which the liquid to be treated must be exposed to the electric field. The exact explanation as to the reason for the improvement resulting from the present invention is not known.

Moreover, it appears that providing a plurality of edges formed by electrode portions 51, 52 and 53 enhances the coalescence of the contaminating water because of the effect of the edges of the electrode portions. However, the effect of the hydrophilic coating is independent of this edge effect although it cooperates with the edges to provide an overall improvement in the removal of water from oil.

While the above embodiment of the invention cites specific materials of construction, it will be obvious to those skilled in the art that alternative materials may be used for specific instances of fluids to be so treated. It is essential only that the materials of construction including insulating covering be suitably resistant to both the fluid to be treated and the contaminating materials. Similarly, it is apparent that a plurality of such devices may be connected in parallel to provide added capacity for the treatment of fluids. In addition, treatment of the fluid by passage through successive stages of such devices is also envisaged with at least partial mechanical removal of larger coalesced droplets of contaminant generated by the treatment between such stages. It is also apparent that these successive treatments may be conducted with varying voltages applied to the electrodes used to generate the electrical fields within such stages with some reduction in power requirement needed to provide an effluent stream of acceptable purity.

While the present invention has been described in detail with respect to the removal of water from oil, it is clear that other contaminants of similar properties can be removed from liquid volumes having dielectric properties like diesel oil.

WHAT WE CLAIM IS:—

1. Emulsion treating apparatus for decreasing the concentration of dispersed contaminant in a substantially nonconductive liquid, comprising first and second electrodes having spaced, facing surfaces substantially parallel to each other and defining therebetween a channel for the liquid, means for applying an alternating or interrupted electric field between the first and second electrodes and across the channel, and means for enhancing the separation of the contaminant from the liquid in the channel through the action of the electric field, the last named means including an insulating covering isolating at least one electrode from the nonconductive liquid and further including a fuzzy hydrophilic substance (as herein defined) positioned on only one of the electrodes so that coalescence of the contaminant is promoted.

2. Emulsion treating apparatus according

to Claim 1, in which the first electrode is insulated and the fuzzy hydrophilic substance is positioned on the second electrode.

3. Emulsion treating apparatus according to Claim 2, in which the first electrode has a high electrical voltage applied thereto relative to the second electrode.

4. Emulsion treating apparatus according to Claim 1, 2 or 3, in which the electrode carrying the hydrophilic substance has an exposed surface to the liquid formed with a succession of edges.

5. Emulsion treating apparatus according to any of Claims 1 to 4, in which the means for applying an electric field is a source of alternating electrical current having a predetermined frequency.

6. Emulsion treating apparatus according to Claim 5, in which the predetermined frequency is 60 Hz.

7. Emulsion treating apparatus according to any of Claims 1 to 6, in which the first and second electrodes are planar plate electrodes positioned in a substantially parallel relationship.

8. Emulsion treating apparatus according to any of Claims 1 to 7, further comprising a container for receiving the nonconductive liquid, the first and second electrodes being positioned in the container.

9. Emulsion treating apparatus according to Claim 8, in which the container is electrically nonconductive.

10. A method of enhancing the effect of an alternating electric field between two electrodes in achieving coalescence of a dispersed immiscible liquid contaminant in a non-conductive liquid stream, the electrodes having spaced, facing surfaces defining therebetween a channel for the liquid, at least one electrode being insulated from the stream, comprising the step of subjecting the liquid stream to an alternating electric field while simultaneously exposing a portion of the stream to a fuzzy hydrophilic substance (as herein defined) positioned on only one of the electrodes within the field to enhance coalescence initiated by the electric field.

11. Emulsion treating apparatus substantially as hereinbefore described with reference to, and as illustrated in Fig. 2 of the accompanying drawings.

12. Emulsion treating apparatus substantially as hereinbefore described with reference to, and as illustrated in Figs. 3 and 4 of the accompanying drawings.

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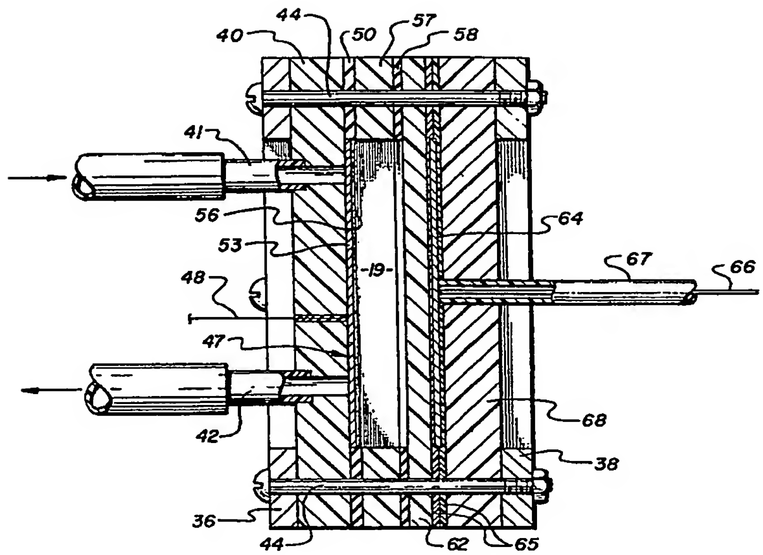
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62
65

FIG. 4

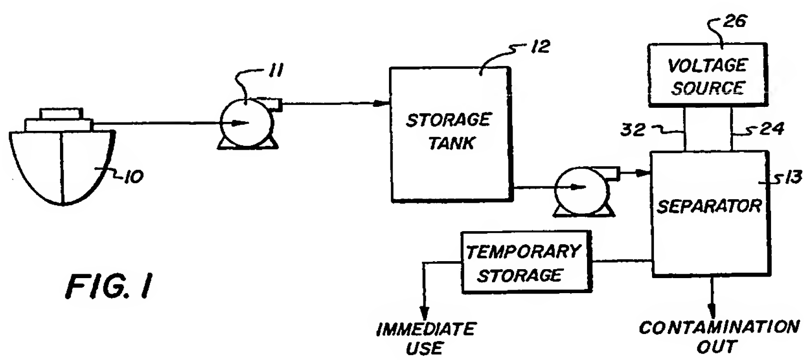
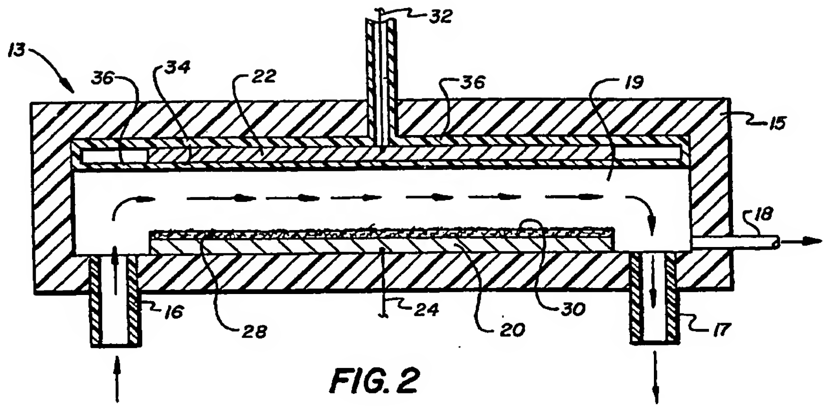

26
VOLTAGE SOURCE
12
11
STORAGE TANK
32
24
13
10
SEPARATOR
TEMPORARY STORAGE
IMMEDIATE USE
CONTAMINATION OUT

FIG. 1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28
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30
17

FIG. 2

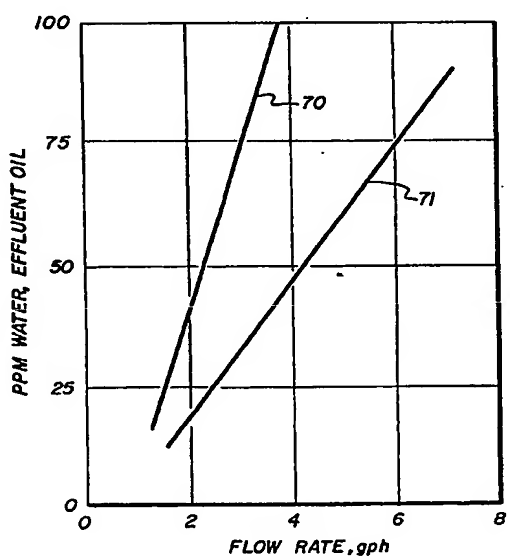
100
75
50
25
0
0
2
4
6
8
PPM WATER, EFFLUENT OIL
FLOW RATE, gph
70
71

FIG. 5

1308470 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

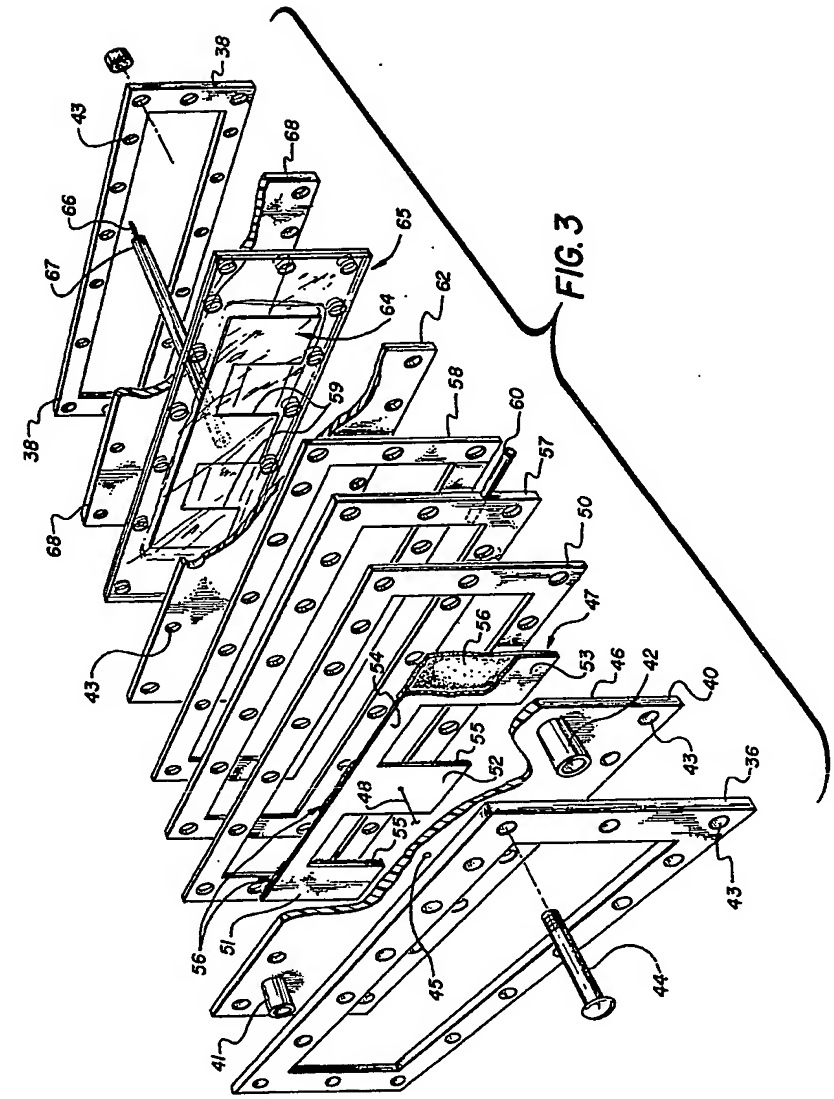

FIG. 3